ENERGY-EFFICIENT CLOTHES DRYERS: AUTOMATIC CYCLE TERMINATION CONTROLLER

Designed and Tested at the Western Cooling Efficiency Center – UC Davis

WCEC's Environmental Test Chamber

PROBLEM

In the interests of promoting energy efficiency and satisfying consumers, there has been a move toward automatic termination controllers in residential dryers, which use some method of sensing to determine when the load is dry. However, available test data shows that these control systems do not fare well when their energy efficiency performance is measured.

To gather data on the effectiveness of the automatic termination controls for dryers, the Department of Energy (DOE) tested eight electric and gas dryers at an independent test laboratory. As described in the DOE publication, *"Energy Conservation Program: Test Procedures for Residential Clothes Dryers; Final Rule"* eight clothes dryers tested with the automatic termination feature used 4-62% more energy than was required to dry the clothes to the remaining moisture content (RMC) standard of 2%. This means that the dryer ran the heat substantially longer than required.

Furthermore, it should be noted that these tests were completed under DOE standard test conditions with new equipment, a specified test load, and where the inlet room air temperature was modulated to be 75±3°F. Performance may vary under different environmental conditions, load types, and as sensor accuracy drifts with time.

SOLUTION

This project developed an automatic dryer cycle termination controller that utilized the relationship between dryer drum inlet temperatures and outlet temperatures to accurately predict the end of the drying cycle. The technology promises to be more accurate and robust in performance under different load and environmental conditions in comparison to existing technology. The low-cost automatic controller was demonstrated in the laboratory to reduce energy use in gas clothes dryers by accurately terminating the drying cycle. In addition, information obtained in the drying cycle can be used to predict real-time energy efficiency metrics to track dryer performance over time as a means for fault detection and to provide information to the consumer.

CONTROLLER DESIGN

Figure 1 illustrates an example drying cycle applying the control algorithm. When the drying cycle begins, the inlet and outlet dryer temperatures are recorded and stored **(1)**. The drum motor, fan, and heating element are activated, and the temperature difference between the dryer drum inlet and the outlet increases. The difference between the inlet and outlet reaches a peak value within a few minutes. The heating element is turned off once the temperature difference decreases to 5% below the peak value (2). Experimental testing at WCEC determined that a 5% drop from the peak value provided a good prediction for when 0.5 lbs of water remained in the load. This correlation held true for various load types and sizes under different environmental conditions.

More information is needed on the size of the load to determine the remaining drying time, because dryness is perceived based on the percentage of moisture content, not on the absolute moisture content. For example, 0.5 lb water is significant in a very small 3.0 lb load, but not in a very large 12 lb load. In order to measure the weight of the load, the load is cooled until the temperature difference between the inlet and outlet temperatures is a steady state value **(3)**. Then, the heating element is turned back on to estimate the current mass of the drum contents **(4)**. The estimation is made based on the maximum rate of change relationship, with respect to time, between the inlet and outlet temperatures, calculated from the stored temperature data **(5)**. The temperature response is a function of the weight of the load because the mass of the load absorbs the heat. Testing at WCEC has shown this to relationship to hold for various load sizes and fabric types.

Now that the remaining water weight and the current load size are known, the dry weight is calculated and the required water removal to reach the desired percent remaining moisture content is determined. The water removal rate near the end of the drying cycle was measured in the laboratory. This rate constant is used to calculate the remaining drying time. Once the remaining drying time is completed, the dryer shuts off **(6)**.

The stored temperature data from the initial heating of the load **(7)** can also be used to estimate the initial weight of the load. The data can be used calculate the total water removed over the cycle in relationship to the drying time to provide real time energy efficiency reporting metrics and fault detection.

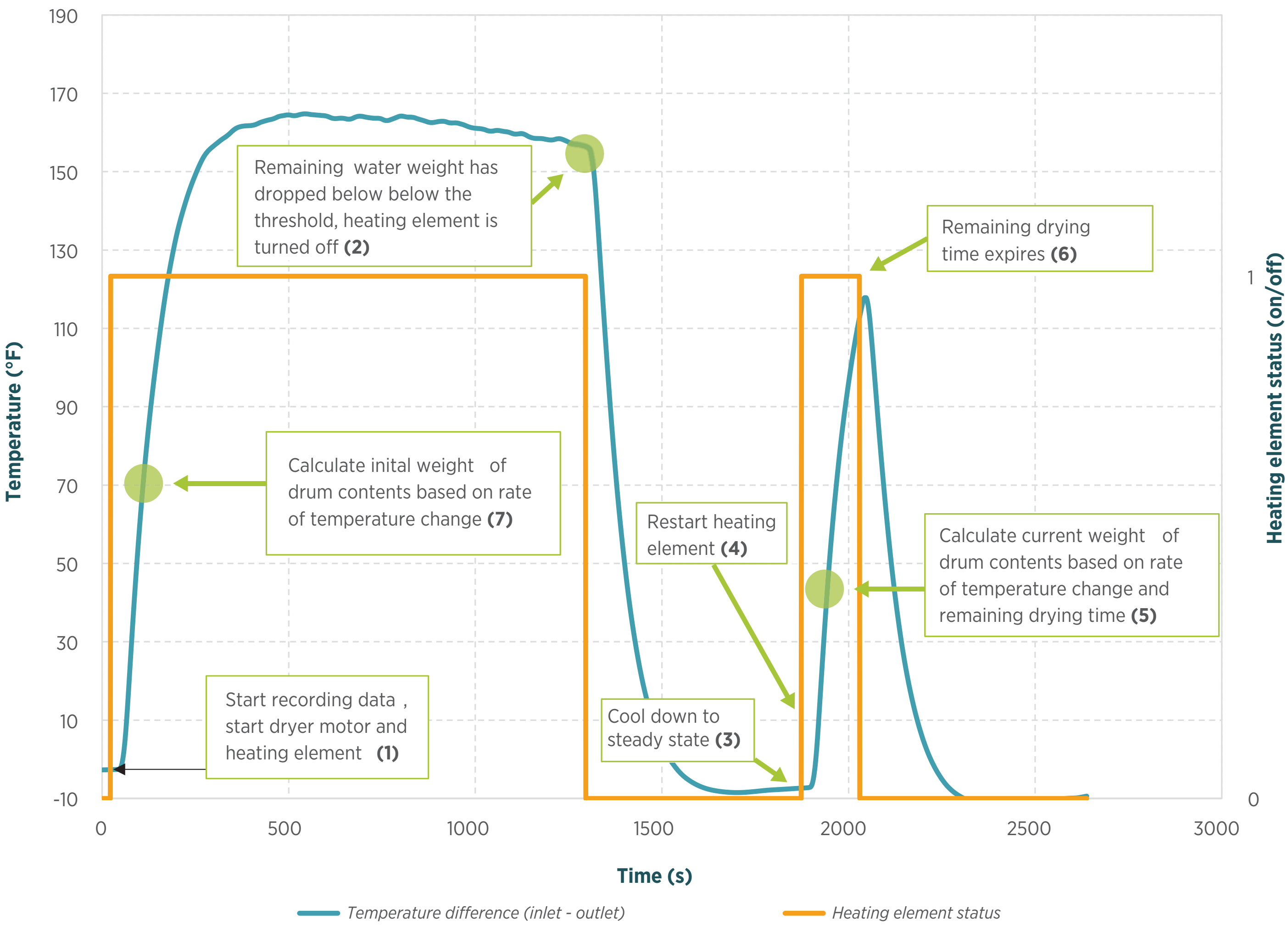

Figure 1: Control algorithm drying cycle example

PERFORMANCE RESULTS

In a standard DOE test conducted three times, the controller shut-off the dryer when 2% remaining content was predicted and measured results showed a remaining moisture content of 1.62%, 1.89%, and 1.93% for the three tests. For drying the DOE standard test load, the controller used between 5-15% less total energy in comparison to three similar gas dryers tested by DOE. The research team calculated that the controller shut-off the dryer within seven seconds of when the dryer reached the desired 2% remaining moisture target.

The research team ran 16 additional tests evaluating the controller over a variety of conditions in which room temperature conditions were varied and load type and size were varied. One test was excluded because a large amount of lint was collected in the drying process which affected the ability to accurately weigh the load at the end of the test. For these 15 tests, the results varied between 1.3 - 6.7% remaining moisture content. All but one test had a remaining moisture content between 1.31 - 5%, where 5% is higher than the DOE test standard of 2%, however, would still be considered "dry" by consumers. The energy consumed for the drying cycles varied between 1.40-4.13 kWh, where the energy consumption was a function of the size and composition of the load. Complete results are available in the report, *"Energy Efficient Clothes Dryers: Automatic Cycle Termination Controller"* available in **the publications section at wcec.ucdavis.edu.**

NEXT STEPS

WCEC seeks a commercial partner to license the technology and implement it in commercial dryers. WCEC has received additional funding from Sacramento Municipal Utility District to test the controller in electric dryers to supplement the testing completed with a gas dryer. The research team also plans to develop the real-time energy efficiency reporting metrics and fault detection capabilities of the technology.

ABOUT WCEC

The Western Cooling Efficiency Center was established along side the UC Davis Energy Efficiency Center in 2007 through a grant from the California Clean Energy Fund and in partnership with California Energy Commission Public Interest Energy Research Program. The Center partners with industry stakeholders to advance cooling-technology innovation by applying technologies and programs that reduce energy, water consumption and peak electricity demand associated with cooling in the Western United States.

PREPARED BY

Theresa Pistochini
Engineering Manager

Caton Mande
Development Engineer

Paul Fortunato
Outreach Manager

Western Cooling Efficiency Center
University of California, Davis
215 Sage Street #100
Davis, CA 95616
wcec.ucdavis.edu